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VULNERABILITY MAPPING APPROACHES OF KARST AQUIFERS ON THE EXAMPLE OF GÖMÖR-TORNA KARST

THESES OF PHD DISSERTATION

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1. Introduction and goals

One of the key issues of our century is to provide sufficient clean drinking water to the growing word population. In the future, the impacts of climate change and the deterioration of the quality of surface waters may increase our appreciation of the fresh water obtained from karst aquifers.

Carbonate terrains cover 12% of the Earth's continental area and 35% of the surface area of Europe. Approximately 20-25% of the global population depends partially or entirely on karst water resources (Ford and Williams 2007). Thanks to its geological structure, Hungary is rich in groundwater of good quality, including also karst waters. Though, taking into consideration the high sensitivity of these resources, the importance of the groundwater protection should not be underestimated by no means (Mádlné Szőnyi 1996).

Karst groundwater protection requires effective and accurate management strategy, which considers the complexity of the hydrological-geological-ecological system of karsts. Emphasis should be placed on prevention tools, as remediation can be complicated, costly and even impracticable if pollution occurs. Vulnerability assessment and vulnerability mapping is an effective tool of prevention (Zwahlen 2004). Groundwater vulnerability maps synthesize the relevant lithological, pedological, hydrogeological, meteorological, hydrological and geomorphological information in a visual and easy-to-understand way (Witkowski et al., 2007). They support decision making in environmental management, land use and water management.

My thesis focuses on the karst groundwater vulnerability approaches, as a topic of internationally high interest, on the example of the Gömör-Torna Karst (Hungary and Slovakia).

The first definitions of groundwater vulnerability were published in the ’70s (Albinet and Margat, 1970). According to one of the first summaries in the topic written in Hungarian “vulnerability is an approximated property of the aquifer, which expresses the capacity of the system (projected to the surface) to compensate the effects of a surficial contamination between the infiltration of the contaminant and the given point of the aquifer” (Mádlné Szőnyi 1997). Due to their special characteristics and different behavior compared to porous aquifers, the research and conservation strategies of karst aquifers require special toolset, which must be based on the understanding of groundwater flow systems (Iván and Mádl-Szőnyi, 2017).

The most frequent issue in vulnerability studies is, that vulnerability assessment schemes are often “automatically” applied, without validating or interpreting the results in the light of the properties of flow and environmental systems. Orientation in the diverse literature of vulnerability causes further difficulties, like non-optimal method choices. Another deficiency is that almost every approach considers vulnerability as a static property, although – especially in karst aquifers – the dynamic hydrological changes of the system would justify the evaluation of temporal variations of vulnerability as well. Regarding the vulnerability assessments carried out in Hungarian sites, a further problem is the lack of good practices.

Based on these issues, I set the following main goals for my thesis:

1. To give a comprehensive, systematic overview of the methodology and literature of karst groundwater vulnerability, which facilitates the optimal method choice, taking into consideration the needs and opportunities of usage on national level.
2. To highlight the potential deficiencies and problematic points in the methodology of karst groundwater vulnerability mapping, as well as the possible and desirable directions for further research.
3. To adapt vulnerability approaches and supplementary research techniques to the usage in national practice and apply them for the examination of the test site on the Gömör-Torna Karst.
4. To synthetize the results and present a process-based, dynamic vulnerability approach placed into hydrogeological context, which is applicable for further Hungarian (and characteristically similar) test sites.

2. Methods

As a first approach I applied the semi-quantitative, parametric Slovene Method. After evaluating the resource vulnerability, I assessed the source vulnerability of the Kis-Tohonya Spring. Revealing the contrast between the rough evaluation and the importance of the aquifer fracturation and the overlying clayey sediments, I presented supplementary field and laboratory investigations. I applied Radiomagneto-tellurics (RMT) and Vertical Electric Sounding for the investigation of sediment thickness and aquifer fracturation. To supplement my own measurements, I analysed the RMT results of the Geogold Kárpátia Ltd. and the Aggtelek National Park as well (Gruber et al. 2015). By means of hydrometry and laser-diffraction methods, I

analysed the grain-size distribution of the soils and sediments and calculated their hydraulic conductivity.

These previous studies facilitated the assessment of a process-based resource vulnerability mapping. The methodology was based on the Time-Input method of Kralik and Keimel (2003) and applied on the areas analysed more in detail. The adapted and modified method is suitable for the karst areas of the region and gives reliable information for resource vulnerability. The vulnerability is expressed in real travel time values instead of dimensionless vulnerability categories.

A common drawback of the vulnerability approaches in groundwater management is that they handle vulnerability as a static property, and they do not provide information about its temporal changes. In order to approach the dynamic aspects of source vulnerability, I analyzed the master recession curves generated from the hydrographs of four springs (Kis-Tohonya, Lófej. Nagy-Tohonya and Jósva Springs). The assessment was based on the methodology and software of Gregor and Malik (2012a, b, c). I complemented and modified the methodology according to the goals of the study. I analyzed 40-50 years long data series. The most important data source was the long-term hydrometeorological database of Maucha (1998). The proposed methodology is appropriate for further usage to generate indexes describing source vulnerability.

3. Results, thesis of the dissertation

In my thesis I presented a process to arrive to a dynamic, process-based vulnerability approach, starting from a simpler parametric analysis and applying supplementary examinations.

The proposed methodology is applicable for the vulnerability analysis of other Hungarian karst areas. Since certain steps of the research require field investigations, naturally the costs are higher compared to a vulnerability procedure based solely on literature data and base maps. Nevertheless, the latter results, particularly on heterogeneous karst areas, are advisable to use only for general, preliminary orientation. The appropriate analysis of the karst systems with both spatially and temporally changing characteristics can be carried out through local scale, comprehensive studies, supported by field measurements.

Based on my research I concluded the following results and thesis:

1. I presented a transparent systematic survey of the approaches in the international literature and summarized the methodological issues and actual trends. This methodological chapter facilitates the comparison of the methods, the consideration of their advantages and disadvantages, thus it helps to optimize the method selection and the proper vulnerability assessment.

2. I gave a general characterization of the resource vulnerability and source vulnerability of the Kis-Tohonya Spring by using the parametric Slovene Approach. I concluded that in terms of resource vulnerability the evaluation of the overlying layers and the fracturation are the most questionable. In terms of source vulnerability, I marked the static approach as the most significant source of problems. For the correction of these issues I proposed supplementary examination techniques.

3. I concluded that radio-magnetotellurics is highly appropriate for detailed vulnerability assessments of karst areas covered mostly by clayey sediments of heterogeneous thickness. Due to their low

hydraulic conductivity, these deposits may effectively decrease vulnerability. Because of their highly varying thickness though, only local scale studies are appropriate to deal with this function. Thanks to the big resistivity contrast between the clayey sediments and carbonates, by using RMT, the thickness of the overlying sediments is well mappable.

4. I deduced as a novel approach, that in case only one-directional RMT measurements are feasible (because of either lacking appropriate radio transmitters, either lacking financial resources or time), one-directional measurements can also be used to derive qualitative information regarding the fracturation of the aquifer. As a sign of anisotropy, the standard deviation values resulting from the evaluation of the RMT data, are appropriate to create qualitative fracturation intensity maps, which can be used as input data for a detailed vulnerability assessment. Multidirectional VES measurements can be used to make the resulting map more accurate. Brion (1976) demonstrated that by means of multidirectional VES measurements the fracturation of karst areas can be mapped. I pointed out, that the methodology, revealing the intensity and mean directions of fracturation is appropriate also for vulnerability studies.

5. Vast majority of the vulnerability studies evaluates vulnerability, as a static property. I pointed out, that from the point of view of resource vulnerability indeed the „where?" is the primary question, though from the point of view of source vulnerability the question „when?" cannot be neglected neither (where and when might preventive actions be necessary). Accordingly, I proposed a dynamic source vulnerability approach.

6. Based on the description of Gregor and Malik (2012a), I proposed a refined and complemented methodology for recession curve analysis of springs, according to its usage in vulnerability assessment. The primary goal of the proposed master recession curve analysis is to separate baseflow (matrix flow) and conduit flow, based on the recession curve analysis. In order to refine the creation of master recession curves, average curves are assessed, while the comparison with measured data enhances the verification of the reliability of the recession equations. The advantage of the method in comparison with others is the low data need, thus the analysis can be carried out for most of the springs (the longer and better resolution the data series is, the more precise).

7. By analyzing the master recession curves of the springs (Kis-Tohonya, Lófej, Nagy-Tohonya and Jósva Springs), I assessed their characteristic recession equations and the typical length of the flood periods.

8. Based on the Time-Input method (Kralik and Keimel, 2003) I proposed a process-based vulnerability approach, which is appropriate for Hungarian (or in their characteristics, similar) karst areas and provides more reliable and tangible results compared to parametric methods.

9. I proposed the usage of the Q_t threshold discharge and the $Q_{conduit}/Q_{matrix}$ ratio, as two dynamic indicators of vulnerability. The Q_t threshold discharge is a detectable breakpoint on the recession curve, above which the fast conduit flow is expected to contribute to the spring discharge. Thus, the threshold discharge index can be used as an early warning about reaching a higher state of vulnerability.

Additionally, the temporal change of the $Q_{conduit}/Q_{matrix}$ ratio expresses the intensity and length of the higher vulnerability state. These two indicators can be assessed by means of the presented recession curve analysis for any spring, if appropriate discharge data series is available.

10. In the frames of the vulnerability analysis of a test site on the Gömör–Torna Karst I assessed vulnerability maps and vulnerability indicators based on field measurements and analysis of long-term time series.

REFERENCES

Albinet, M. and Margat, J., 1970, Cartographie de la vulnerabilité à la pollution des nappes d'eau souterraines: Bull. BRGM, v. 2ème série, no. 3(4), pp. 13-22.

Brion, M., 1976, L'etude du phenomene de l'anisotropie electrique appliquee au milieu carbonate fracture: Universite des sciences et techniques du Languedoc.

Ford, D. and Williams, P. D., 2007, Karst Hydrogeology and Geomorphology, Wiley.

Gregor, M. & Malík, P., 2012a, Construction of master recession curve using genetic algorithms: Journal of Hydrology and Hydromechanics, v. 60, no. 1, pp. 3-15.

Gregor, M. and Malík, P., 2012b, FlowComp 2.0 User's Manual.

Gregor, M. and Malík, P., 2012c, RC 4.0 User's Manual.

Gruber P., Gaál L., Balázs I., Mátrahalmi T., Serfőző A. és Ambrus M., 2015, Geofizikai vizsgálatok a Haragistya–Szilice–Borzova karsztterületen (HU-SK). Karsztfejlődés, V. 20, pp. 81-99. [in Hungarian]

Iván V. and Mádl-Szőnyi J., 2017, State of the art of karst vulnerability assessment: overview, evaluation and outlook: Environmental Earth Sciences, v. 76, no. 3, pp. 112-137.

Kralik, M. and Keimel, T., 2003, Time-input, an innovative groundwater-vulnerability assessment scheme: application to an alpine test site: Environmental Geology, v. 44, no. 6, pp. 679-686.

Mádlné Szőnyi J., 1996, Víztartó rendszerek sérülékenységi vizsgálata. Elméleti háttér és gyakorlat. [in Hungarian]

Mádlné Szőnyi J., 1997, Víztartó rendszerek sérülékenységi vizsgálata a dunántúli-középhegységi főkarsztvíztároló rendszer (DNy-i rész) példáján: Földtani Közlöny, v. 127, no. 1-2, pp. 19-83. [in Hungarian]

Maucha L., 1998, Az Aggteleki-hegység karszthidrológiai kutatási eredményei és zavartalan hidrológiai adatsorai. 1958-1993. VITUKI Rt. Hidrológiai kiadványa, p. 414. [in Hungarian]

Witkowski, A. J., Kowalczyk, A. és Vrba, J., 2007, Groundwater Vulnerability Assessment and Mapping: IAH-Selected Papers, Taylor & Francis.

Zwahlen, F., 2004, Vulnerability and risk mapping for the protection of carbonate (karst) aquifers, final report (COST action 620). European Commission, Directorate-General XII Science.

PUBLICATIONS RELATED TO THE PHD DISSERTATION

Iván V. and Mádl-Szőnyi J., 2017, State of the art of karst vulnerability assessment: overview, evaluation and outlook: Environmental Earth Sciences, v. 76, no. 3, pp. 112-137.

Iván V. and Mádl-Szőnyi J., 2017, Vulnerability assessment and its validation: the Gömör-Torna Karst, Hungary and Slovakia: Geological Society, London, Special Publications, v. 466, pp. 261-273.

Iván V., Móga J., Fehér K. és Miklós B., 2011, Karsztsérülékenységi vizsgálatok a bükki Kis-fennsík karsztján: Karsztfejlődés XVI. Szombathely, pp. 167-183. [in Hungarian]

Móga J., Strat, D., Iván V., Mari L., Kiss K., Szabó M., Borsodi A. és Csüllög G., 2017, Changes of the karst landscape and epikarst system in the area of the Tapolca karst terrains, North-West Balaton Highlands, Hungary, in Proceedings Forum Geografic 2017, Volume 16, University of Craiova, Department of Geography, pp. 12-25.

OTHER PUBLICATIONS

Mádl-Szőnyi J., Czauner B., Iván V., Tóth Á., Simon S., Erőss A., ... & Sőreg V. 2017, Confined carbonates–Regional scale hydraulic interaction or isolation? Marine and Petroleum Geology, pp. 1-22.

Móga J., Szabó M., Mari L., Borsodi A., Kéri A., Knáb M., Kiss K., Iván V., 2014, Természeti és antropogén hatásokra végbemenő tájváltozások vizsgálata a Bakonyban. Földrajzi Közlemények 138:(2) pp. 89-106. [in Hungarian]

Móga J., Kiss K., Szabó M., Kériné Borsodi A., Kéri A., Mari L., Knáb M., Iván V., 2013, Hazards and Landscape Changes (Degradations) on Hungarian

Karst Mountains Due to Natural and Human Effects. Journal of Mountain Science 10:(1) pp. 16-28.
Móga J., Kiss K., Szabó M., Kériné Borsodi A., Kéri A., Mari L., Knáb M., Iván V., 2011, Természeti és antropogén hatások vizsgálata a Tapolcai-karszt epikarsztos rendszerébe Karsztfejlődés 16: pp. 185-201. [in Hungarian]

CONFERENCE PROCEEDINGS RELATED TO THE PHD DISSERTATION

Iván V. and Mádl-Szőnyi J., 2018, Possibilities of recession curve analysis in karst water management, Gömör-Torna Karst, Hungary and Slovakia. In: EGU General Assembly: Geophysical Research Abstracts. Paper EGU2018, p. 14399.
Mádl-Szőnyi J., Czauner B., Iván V., Tóth Á., Simon S., Erőss A., ... & Bodor P., 2017, Deep seated carbonates and their vulnerability-are they isolated or hydrodynamically interacted? In EGU General Assembly Conference Abstracts, Vol. 19, p. 8381.
Iván V. and Mádl-Szőnyi J., 2017, Groundwater vulnerability assessment and validation on the example of Gömör-Torna Karst, Hungary and Slovakia. In EGU General Assembly Conference Abstracts, Vol. 19, p. 15184.
Iván V., Balázs I., Mátrahalmi T., Mádl-Szőnyi J., Gruber P., 2015, Karst groundwater vulnerability assessment with the help of geophysical techniques, Gömör-Torna Karst, Hungary and Slovakia. In: Witkowski et al (ed.) Groundwater Vulnerability: From Scientific Concept to Practical Application. Ustron, Poland, 2015.05.25-2015.05.29. p. 34.
Iván V. and Mádl-Szőnyi J., 2015, Gravity-driven groundwater flow as part of the best professional synthesis in karst vulnerability assessment. In: A J Witkowski et al (ed.) Groundwater Vulnerability: From Scientific Concept to Practical Application. Ustron, Poland, 2015.05.25-2015.05.29. p. 35.
Iván V. and Móga J., 2013, Comparative application of vulnerability mapping methods on Hungarian karst areas. In: Judit Mádl-Szőnyi, Anita Erőss, Andrea Mindszenty, Ádám Tóth (eds.) International Symposium on Hierarchical Flow Systems in Karst Regions: In honour of Professor József Tóth in celebration of his 80th birthday. 201 p. Budapest, Hungary 2013.09.04-2013.09.07. p. 84.
Iván V., 2013, Comparative Analysis of Vulnerability Mapping Methods on a Hungarian Karst Area. In 2013 NGWA Summit—The National and International Conference on Groundwater, San Antonio, USA.